GROUND-COUPLING WITH WATER SOURCE HEAT PUMPS

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Ground-coupled heat pumps (GCHPs) have been receiving increasing attention in recent years. In areas where the technology has been properly applied, they are the system of choice because of their reliability, high level of comfort, low demand, and low operating costs. Initially these systems were most popular in rural, residential applications where heating requirements were the primary consideration. However, recent improvements in heat pumps units and installation procedures have expanded the market to urban and commercial applications.

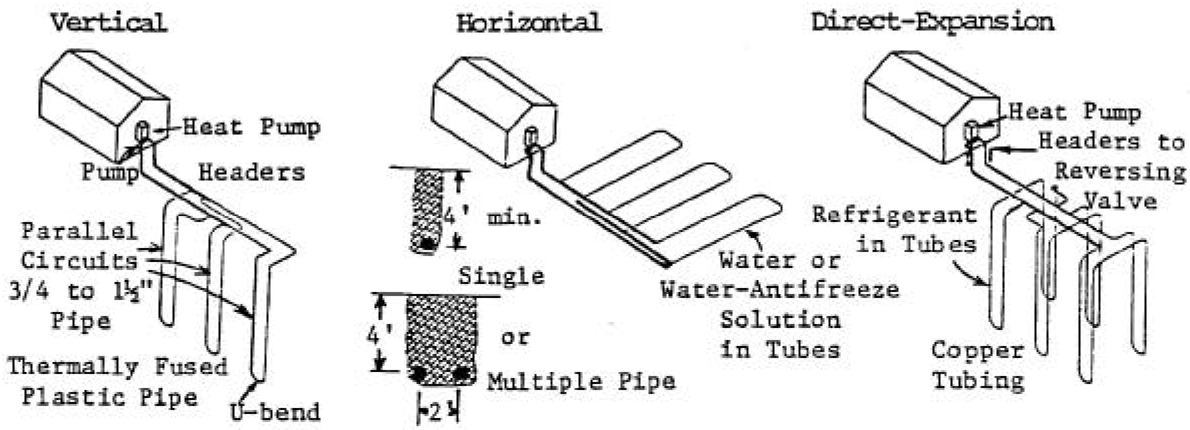
This paper discusses some of the current activity in the commercial sector. The basic system and nomenclature are discussed. Several variations for commercial buildings are presented along with examples of systems in operation. Several advantages and disadvantages are listed. Operating and installation costs are briefly discussed. Finally, the GCHP is presented as an alternative that is able to counter much of the criticism leveled by the natural gas industry toward conventional heat pumps.

NOMENCLATURE

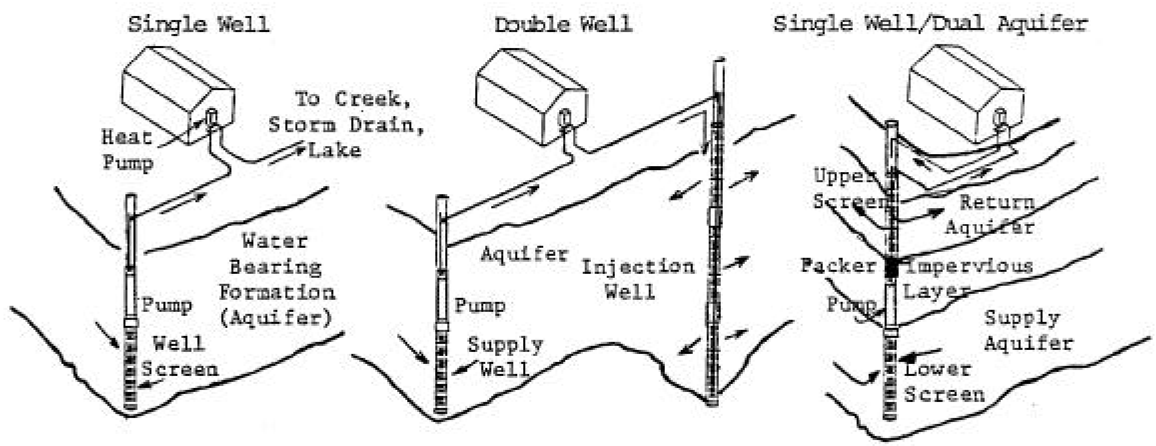
There are a variety of names for ground-coupled heat pumps. These include ground-source heat pumps, earth-coupled heat pumps, earth energy systems, ground source systems, geothermal heat pumps, closed-loop heat pumps, and solar energy heat pumps. Much of the confusion arises from local marketing needs. Sales people may wish to connect GCHPs to renewable energy sources (solar, geothermal), disassociate them from air heat pumps (GS systems), or connect them to environmental awareness (earth energy). A generally (although not universally) recognized nomenclature is shown in Figure 1.

Ground-coupled heat pumps are a subset of ground-source heat pumps (GSHPs). GSHPs also include groundwater and lake water heat pumps. The distinguishing feature of GCHPs is that they are connected to a closed-loop network of tubing that is buried in the ground. The most common method of ground-coupling is to bury thermally fused plastic pipe either vertically or horizontally. A water or antifreeze solution is circulated through the inside of the tubing and heat is released to or absorbed from the ground. No water enters the system from the ground. Water-to-air heat pumps are located inside the building and are connected to the water loop with a circulator pump. This type of system is referred to as a secondary fluid GCHP since there is an intermediate liquid between the refrigerant and the ground.

I. GROUND-COUPLED (Earth Coupled, Closed Loop Geothermal, GT System, etc.)



II. GROUND WATER (Open Loop Geothermal, Open Loop Ground Source)



III. LAKE WATER (Pond Loop, Surface Water Loop)

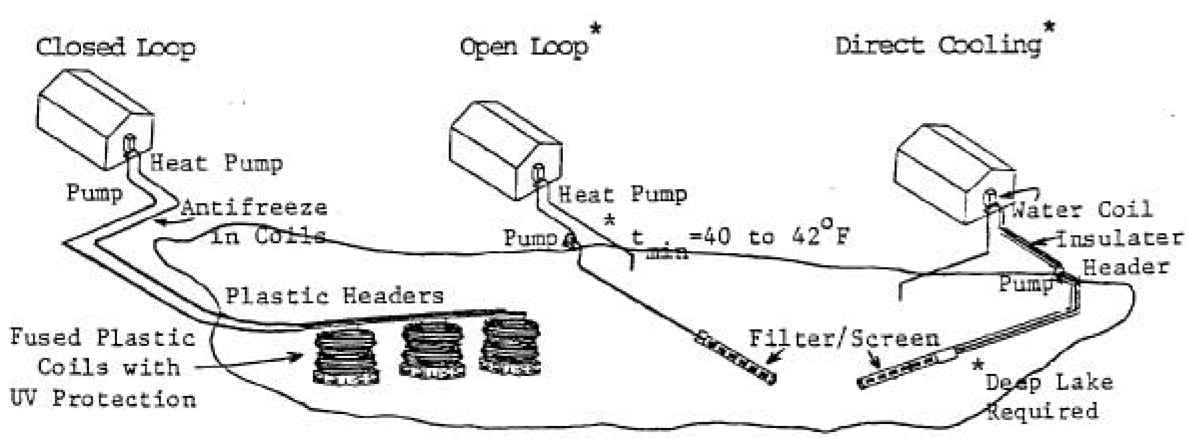


Figure 1. Ground-Source Heat Pump Types Including Ground-Coupled, Groundwater, and Lake Water Heat Pump Systems

A less frequently used system is referred to as a direct expansion (DX) GCHP. Refrigerant lines are buried in the ground in either a vertical or horizontal arrangement. Thus the intermediate heat exchanger and fluid are eliminated. The possibility of higher efficiency than secondary fluid GCHPs does exist. However, larger charges of refrigerant are required and system reliability is compromised. Therefore, the future of DX GCHP is not clear because of environmental concerns.

COMMERCIAL BUILDING APPLICATIONS

GCHPs are often confused with a much more widely used commercial system, the water loop heat pump (WLHP) or water source heat pump. Although the piping loop inside the building is similar, there are several important differences. Figure 2 is a diagram of conventional WLHP. Water-to-air heat pumps are located throughout the building. Local zone temperature is achieved with conventional on-off thermostats. Ductwork is minimized because the units are in the zone they serve. A central piping loop is connected to all the units. The temperature of this loop is typically maintained between 60°F (16°C) and 90°F (32 °C). A cooling tower is used to remove heat when the loop temperature exceeds 90°F and heat is added with a boiler if the temperature falls below 60°F.

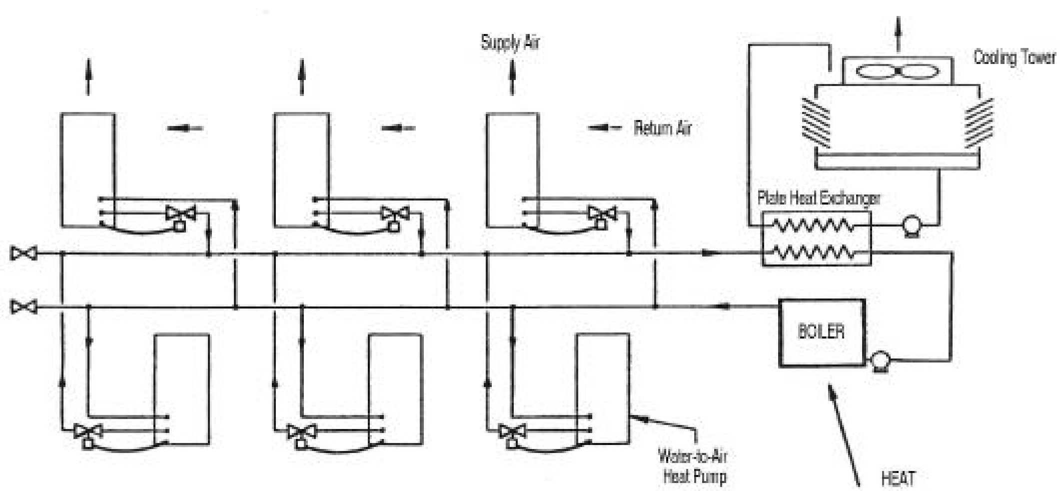


Figure 2. Conventional Water-Loop Heat Pump System

WLHPs are most successful when internal building loads are sufficient to balance the heat loss through the external surfaces and ventilation. If heat losses exceed internal loads, the energy requirements of WLHPs can become significant. Energy must be added in both the boiler and heat pumps. This is not true in cooling because the heat is dissipated through the cooling tower which only had pump and fan motor requirements.

Figure 3 is a diagram of a GCHP loop in a commercial building. The boiler, the cooling tower, and the associated pump and heat exchanger have been replaced with the buried piping system. The only remaining auxiliary is the loop circulation pump. Heat is added to or removed from the ground at no cost and no energy is required to operate a boiler or cooling tower.

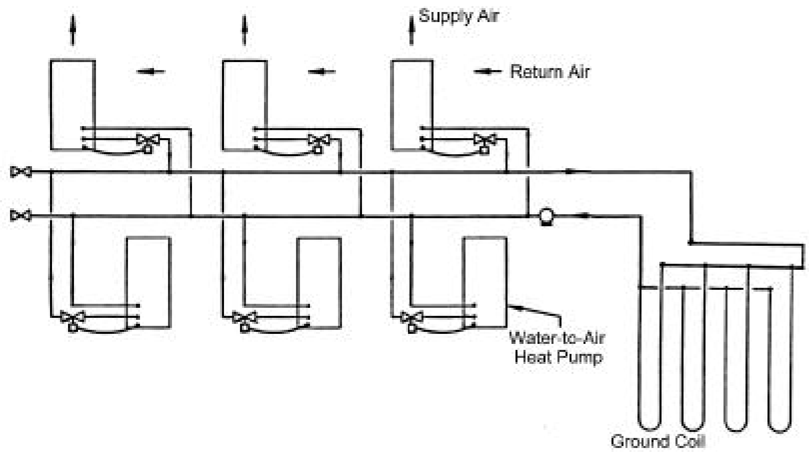


Figure 3. Ground-Coupled Heat Pump System

The diagram does not show an important distinction between the water-to-air heat pumps used in GCHP systems. WLHPs are designed to operate in the narrow range of 60 to 90 °F. They will not perform adequately in a GCHP system. The units used in GCHP systems must be extended range water-to-air heat pumps. Some manufacturers create extended range heat pumps by replacing the fixed expansion device of a WLHP with an thermostatic expansion valve (TEV). Others make this modification and add improved compressors, air and water coils, fans, and controls. This has resulted in units that operate with higher efficiencies than a conventional WLHPs even when operating with water temperatures outside the 60 to 90°F range.

It is obvious that the ground coil can add to the cost of the system. Also many high rise commercial applications may not have sufficient land area to accommodate a full size ground coil. A hybrid ground-coupled water-loop heat pump (GCWLHP) would be a viable option to reduce the size of the ground coil. The coil would be sized to meet the heating requirement of the building. This is typically one-half the size required for meeting the cooling load. There are several reasons for the smaller size.

* In the heating mode only about 70% of the heat requirement of the building must come from the ground coil. The remaining 30% comes from the power input to the compressor and fan motors. So the coil transfers about 8,400 Btuh/ton. In cooling the coil must transfer the building load and the added heat of the motors. This means 130% or 15,600 Btuh/ton, must be moved through the ground coil.

* The cooling requirement of commercial buildings with high lighting and internal loads usually exceeds the heating requirement.

* The heating requirement is commercial buildings is often in the form of a morning "spike" followed by a reduced load. Ground coils are well suited to handling spikes because of the large thermal mass of the earth. Therefore, lengths can be reduced compared to systems designed for continuous loads.

Since the ground coil for a GCWLHP would not be able to meet the cooling load in most climates, a downsized cooling tower would be added to the loop as shown in Figure 4.

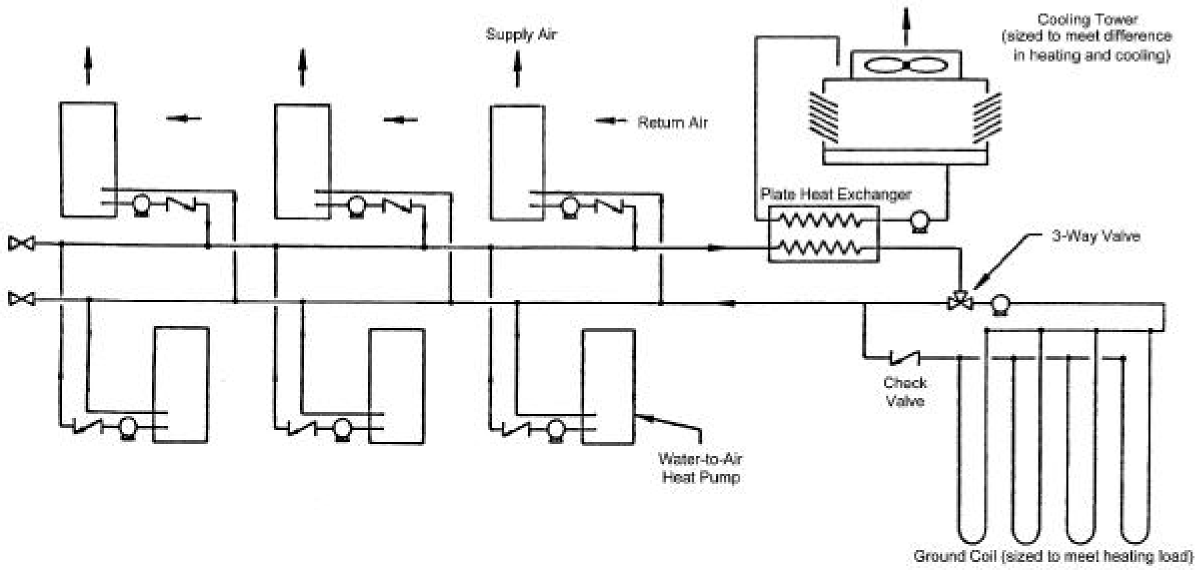


Figure 4. Water-Loop Ground-Coupled Heat Pump System

GCHPs can also be integrated into "free cooling" or thermal storage schemes. For example, hydronic coils could be added to core heat pumps of a GCWLHP system. When the outdoor temperature was cold enough the cooling tower could be started. This would bring the loop temperatures below 50 °F (10°C) to cool the core zones without activating the compressors. The heat pumps in perimeter zones could operate simultaneously in the heating mode if required. A variety of other systems are possible because of the simplicity and flexibility of ground-coupled heat pumps.

EXAMPLES OF COMMERCIAL INSTALLATIONS

Very few building owners, engineers, and architects consider GCHPs becuse in the past implements was difficult. There were very few qualified loop installers, design guides were hard to find, and the traditional HVAC&R network balked at the thought of linking equipment to plastic pipe buried in the ground. However, the experiences of those who tried this"new" concept have led to a sound methodology for the design and installation of highly reliable and efficient systems.

One such firm operates in Pennsylvania. This firm designs, installs and operates GCHP systems. The ground coils are typically 200 to 500 ft. deep with 1½ inch (4cm) polyethylene U-bends. Drilling in the area is very difficult compared to the rest of the U.S.A. However, several successful systems have been and are continuing to be installed and operated. A listing is given in Table 1.

TABLE 1. Listing of Systems Installed and Operated by Pennsylvania GCHP Firm

Building Type	Area (sq. ft.)	Capacity Tons	# Units	# Bores
Bank	5,500	13	3	3
Retir. Community	420,000	840	316	187
Elem. School	24,000	59	21	20
Doctor's Office	11,800	35	7	7
Condominiums	88,000	194	74	40
Middle School	110,000	412	96	106
Restaurant	6,500	36	6	7
Office/Lab	104,00	252	43	62
Elderly Apts.	25,000	89	76	12
Life Care Comm.	390,000	1,100	527	263
Ron. McDonald House	2,000	5	4	1

Similar firms are operating profitably in areas all over the country. Austin, Texas has several new schools and other commercial buildings that have GCHPs. Activity in Canada is very high compared to the U.S. with utilities promoting the technology with rebates and technical assistance. Oklahoma, a state that derives much of its income from oil and gas, is in the process of installing a GCHP system to heat and cool its state capital complex.

The common thread in successful GCHP programs appears to be an individual or set of individuals in a particular location who recognize the advantages of GCHPs. These individuals have the initiative to push forward in spite of the many skeptics who contend that GCHPs will not work.

ADVANTAGES OF GCHPS

Efficiency

Heat pump efficiency is primarily dependent upon the temperature difference between the building interior and the environment. If this difference can be minimized, heat pump efficiency (and capacity) will improve. Ground temperatures are almost always closer to room temperature than air temperatures. Therefore, GCHPs are inherently more efficient than units that use outdoor air as a heat source or sink if the ground coil is correctly designed. This principle is one of Mother Nature's rules and is referred to as Carnot's Law.

Secondly, it is important to have large coils for high efficiency. (Compare today's outdoor units with those used 20 years ago). Water is far superior to air with regard to "convecting" heat through coil surfaces. Therefore, the water coils in GCHP are smaller and much more "efficient" in transferring heat.

The part-load efficiency of a GCHP is actually improved compared to full load efficiency. When the ground coil is partially loaded, the water loop temperature more closely approaches the earth temperature. This temperature is cooler in the cooling mode and warmer in the heating mode. Therefore, system efficiency is improved.

Auxilary power requirement can be reduced significantly compared to conventional systems. In addition to being a better heat transfer fluid compared to air, water requires much less energy to be circulated. Although it is heavier than air, a given volume of water contains 3500 times the thermal capacity of atmospheric air. Therefore, the pump motors circulating water through a GCHP system are much smaller than outdoor air or cooling tower fan motors of conventional systems. The indoor fan power is also reduced because the units are in the zone and duct runs are very short and non-existent. Therefore, low pressure (and power) fans can be used.

Unfortunatly, the efficiency ratings used for GCHPs do not match with the ratings of conventional equipment. For comparison consider a cental chiller and GCHP. Table 2 is a comparison of the full load efficiency of a 100 ton central chiller to a GCHP.

Space

GCHP systems require a small amount of space if properly designed. A 5 ton (18 kW) water-to-air heat pump in a horizontal package can be as small as 20x25x45 inches (50x64x115cm) and easily located above the ceiling in a typical office. Vertical packages can be place in small closets. Some units used in WLHP systems may have excessive noise levels for these locations. However, the improved units recommended for GCHP systems have quieter compressors and large, low velocity fan wheels that reduce noise levels.

TABLE 2. Efficiency Comparison of High Efficiency Central Chiller with GCHP

1. Chiller @ 85°F Cond. water and 45°F chilled water (0.6 kW/ton)	60 kW
2. Indoor fans (40,000 cfm, 3.0 in. ESP, 90% motors)	25 kW
3. Cooling tower fan (5 hp)	4 kW
4. Cooling tower pump (5 hp)	4 kW
5. Indoor circulation pump (5 hp)	4 kW
Total	97 kW

Efficiency = 0.97 kW/ton (EER = 12 ÷ 0.97 = 12.4)

1. 20 - 5 Ton w/a heat pumps, 85°F EWT, scroll compressor, ½ hp fan (4.24 kW each)	85 kW
2. Indoor Circulation pump (5 hp)	4 kW
Total	89 kW

Efficiency = 0.89 kW/ton (EER = 12 ÷ 0.89 = 13.5)

The central distribution system requires relatively little space. Figure 5 shows the relative requirements for a high velocity air system, a low velocity air system, and a GCHP. The figure also indicates the required power of the GCHP pump is much smaller than the fans of either air system.

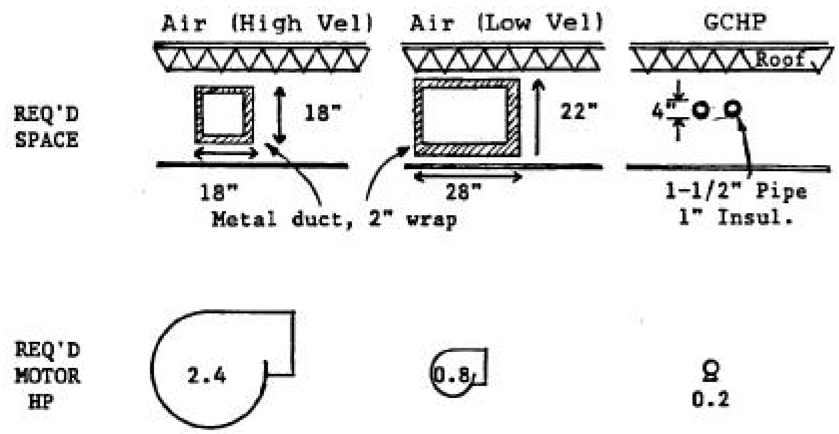


FIGURE 5. Space and Power Requirements for HVAC Distribution (Based on 10 tons being transported 100 feet.)

Aesthetics

One pleasant advantage of a GCHP system is the absence of unsightly outdoor equipment. The ground above outdoor coil can become a greenspace or a parking lot. This is especially suited to schools where outdoor equipment may pose a safety hazard to small children or a vandalism target for not so small children.

Simplicity

The conventional GCHP system is extremely simple. The water-to-air unit consists of a compressor, a small water coil, a conventional indoor air coil, one bi-flow expansion device, and a few electrical controls. The flow control can be either a single circulation pump on each unit (that is turned on with the compressor relay) or a normally closed two-way valve for systems with a central circulation pump. If the designer chooses an extended range heat pump as recommended, no water regulating control valves are necessary.

Control

Control is also very simple. A conventional residential thermostat is sufficient. Since units are located in every zone, a single thermostat serves each unit. Zones can be as small as ½ ton (1.8 kW). However, each unit can be linked to a central energy management system if desired. Air volume control is not required. Larger water-to-air heat pumps are available if multi-zone systems are required. This would complicate one of the most attractive benefits of GCHPs, local zone control. The simple system can be installed and serviced by technicians with moderate training and skills. The building owner would no longer be dependent on the controls vendor or outside maintenance personnel. The simple control scheme would interface with any manufacturers thermostats.

Comfort

GCHPs eliminate the Achilles' heel of conventional heat pumps in terms of comfort, "cold blow". Commercial systems can be designed to deliver air temperatures in the 100°to 105°F (38° to 41°C) range without compromising efficiency. Moisture removal capability is also very good in humid climates. The previously discussed advantage of local zone control is also critical to occupant comfort.

Maintenance

One of the most attractive benefits of GCHPs is the low level of maintenance. The heat pumps are closed packaged units that are located indoors. The most critical period for a heat pump compressor is start-up after defrost. GCHPs do not have a defrost cycle. The simple system requires fewer components. Logic dictates that the fewer components, the lower the maintenance. Because of the limited amount of data for GCHPs, not a great deal of data is available to support the claim of low maintenance in commercial buildings. However, a detailed study of a WLHP system was conducted and the median service life of compressors in perimeter heat pumps was projected to be 47 years (Ross1990).

DISADVANTAGES

New Technology

GCHPs face the typical barriers of any new technology in the heating and cooling industry. Air source heat pump and natural gas heating technology has been successful. The technical personnel have been trained to install and service this equipment. A great deal of research and development has been successfully devoted to improving this technology. Why go to something new?

The GCHP technology faces an additional barrier in the lack of an infrastructure to bridge two unrelated networks: the HVAC industry and the drilling/trenching industry. There is little motivation on either side to unite. The HVAC industry prefers to continue marketing a proven technology and well drillers continue to profit on existing water well, environmental monitoring well, and core sampling work. It is the task of the two sectors who benefit the most from GCHPs, customers and electric utilities, to force a merger of the two networks.

Limited Profit for HVAC Equipment Manufacturers

Some equipment manufacturers are resistance to GCHPs because of the reduced need of their products. Water-to-air heat pumps are relatively simple and potentially inexpensive devices. The control network is especially simple and inexpensive. There will be no need for manufacturer's technicians to trouble-shoot and service control systems. There will be no need to lock into one manufacturer's equipment because of incompatibility.

GCHPs are not inexpensive. However, approximately 50% of the system's first cost must be shared with a driller/trencher. Therefore, some HVAC manufacturers may be reluctant to support the implementation of GCHPs.

Installation Cost

The most formidable barrier to GCHP systems is currently high installation costs. While this is especially true in the residential sector, it also applies to commercial applications. Residential premiums compared to a standard electric cooling/natural gas heating system (9.0 SEER, 65% AFUE) are typically $600 to $800 per ton for horizontal systems and $800 to $1000 per ton for vertical systems. Simple payback is typically five to eight years. The percent increase is somewhat less for commercial GCHPs as shown in the following section.

PROJECTED COST OF COMMERCIAL GCHPS

The cost of vertical ground coil ranges between $2.00 to $5.00 per ft. of bore. Required bore lengths range between 125 ft. per ton for cold climate, high internal load, commerical buildings to 250 ft. per ton for warm climate installations. Pipe cost can be as low as $0.20 per ft. of bore ($.10/ft of pipe) for 3/4 inch (2.0 cm) and as high as $1.00 per ft. of bore ($0.50/ft of pipe) for 1½ inch (4.0 cm) polyethylene pipe. Drilling cost range from less than $1.00 per ft. to as high as $12.00 per ft. However, $5.00 per ft. is typically the upper limit for a drilling rig designed for the small diameter holes required for GCHP bores even in the most difficult conditions. It should be noted that larger diameter pipes result in shorter required bore lengths. Table 3 gives typical costs for low and high drilling cost conditions for 3/4 and 1½ inch U-bends for a 10 ton system.

TABLE 3. Cost of Vertical Ground Coils

	$1.50/ft. DRILLING COST		$4.00/ft. DRILLING COST	
	3/4" (2000')	1½"(1700')	3/4" (2000')	1½"(1700')
Drilling	$3000	$2550	$8000	$6800
Pipe	600	1360	600	1360
Fittings	300	300	300	300
TOTAL	$3900	$4210	$8900	$8460
Cost/ton	$390	$421	$890	$846

The table indicates the added cost to be in the $400 to $850 per ton range. With this information we can adapt the results of a comprehensive study on WLHPs (Pietsch). WLHP system costs are plotted in Figure 6. If the cost of the WLHP boiler, drains, and cooling tower is deducted from the total and the cost of the ground coil and current cost of improved heat pumps ($100/ton) is added, a cost range for GCHPs results. For low cost drilling sites the cost of GCHPs is actually lower than conventional 2-pipe VAV systems.

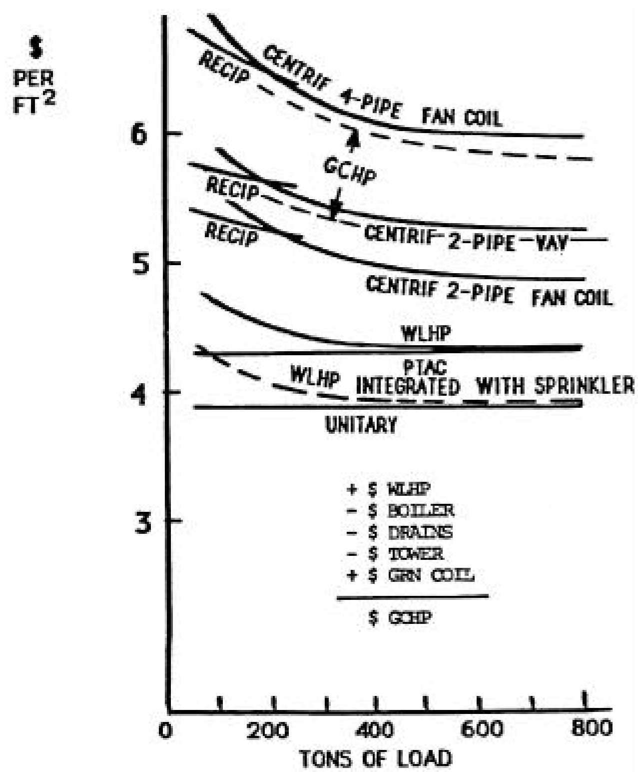


FIGURE 6. Projected Cost of Vertical GCHP Systems
(Adapted from Pietsch 1988)

Operating Costs

Limited data is available documenting the operating cost of GCHPs in commercial applications. The steady state and part load cooling efficiencies of vertical GCHPs appear to be superior to high efficiency central systems. The heating efficiencies are very good, especially when the ground coil is sized to meet the cooling requirement. However, these high efficiencies will not be realized if ground coils are undersized or low and moderate efficiency water-to-air heat pumps are used.

A comprehensive study of GCHP operating costs in commercial buildings should be conducted. This study is needed to expand the limited design guidelines currently available for GCHPs.

FACING THE COMPETITION WITH GCHPS

Figure 7 is a set of diagrams from the pamphlet "Electric Heat Pumps: How Good Are They?" produced by the American Gas Association. Electric utilities may argue that these figures may be exaggerated. There is a strong element of truth in each. Air source heat pumps do not heat well in cold weather (Mother Nature will not allow it). Air heat pumps do blow large amounts of air at temperatures below body temperature. In the heating mode, the air heat pump consumes more net energy than high efficiency gas furnaces.

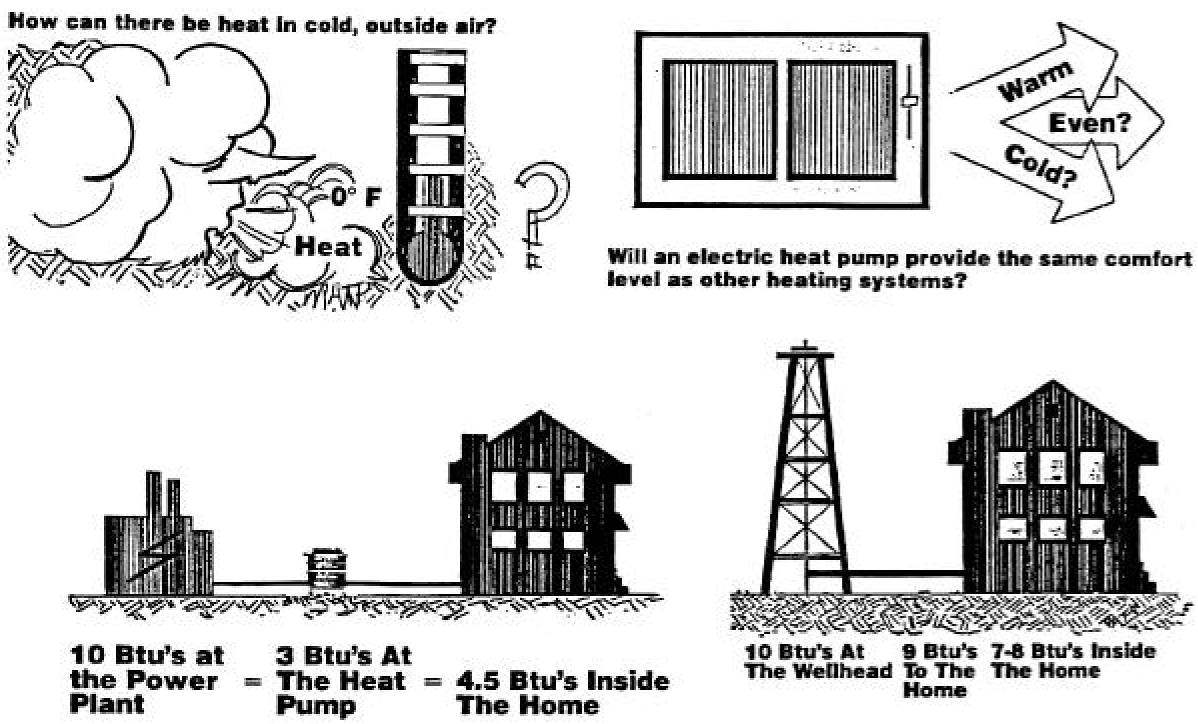


FIGURE 7. Examples of Criticism of Air Heat Pumps

The electrical utility has focused the bulk of its response on aggressive marketing that in some cases is equally as misleading as the AGA's document. This marketing includes advertising and reduced rates for customers who choose electric heat. To a lesser degree, the response has included development of advanced heat pumps. In the commercial sector, this has generally excluded GCHPs. Most of the developmental activity for GCHPs has been confined to the residential market.

If the AGA heat pump document was modified for GCHPs as shown in Figure 8, the electric utility would be the benefactor. Even when the air is 0°F and below, the ground in the U.S.A. is 45°F and above, GCHPs can operate very well and can deliver air at a comfortable temperature. For every 10 Btus used at the power plant at least 10 Btus are delivered to the home.

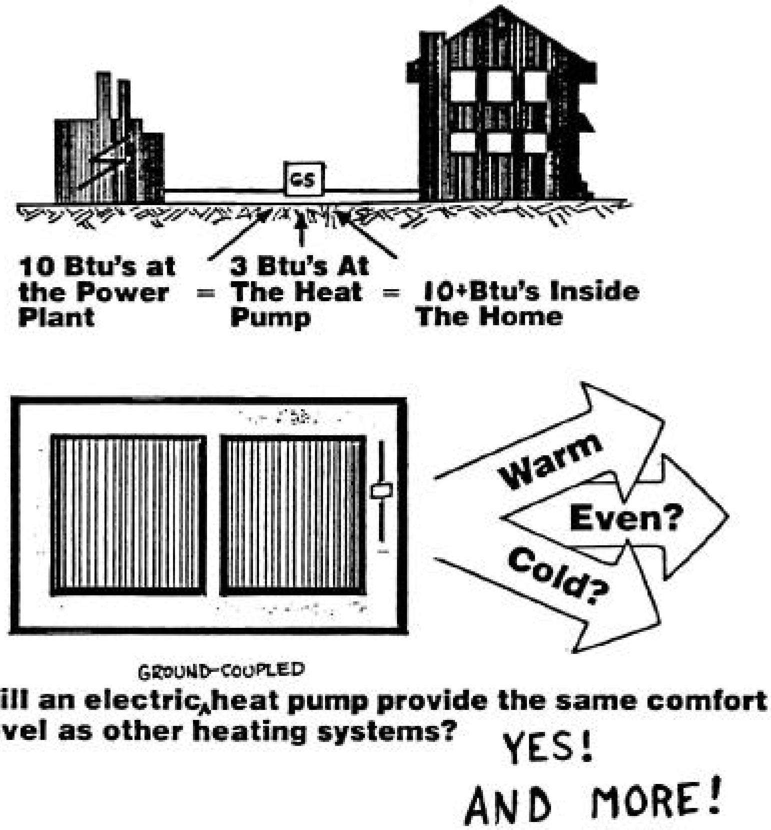


FIGURE 8. GCHP Answers for AGA's Criticism of Heat Pumps

Ground-coupled heat pumps are an improved electric heating and cooling alternative. They offer all of the many advantages of conventional electric heat pumps plus higher efficiency, simplicity, reliability, reduced demand, removal of unsightly outdoor equipment, comfort, and long life. They offer a system whose performance can not be matched by natural gas equipment.

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